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TITLE: Torsional micro-mechanical mirror system

DATE-ISSUED: March 13, 2001

INVENTOR-INFORMATION:

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US-CL-CURRENT: 359/223; 359/291, 359/295, 359/298

CLAIMS:

We claim:
1. A torsional micro-mechanical mirror system comprising:
a base having a cavity formed therein;
a mirror assembly;
a torsional mirror support assembly comprising at least one torsional spring supporting the mirror assembly for rotational movement over and within the cavity, the cavity sized sufficiently to allow unimpeded rotation of the mirror assembly to a preselected maximum angle of deflection; and
an actuator assembly operative to apply a driving force directly to the torsional mirror support assembly to torsionally drive the torsional mirror support assembly, whereby torsional motion of the torsional mirror support assembly causes rotational motion of the mirror assembly.
2. The system of claim 1, wherein the mirror assembly comprises a support structure coplanar with the base.
3. The system of claim 1, wherein the mirror assembly comprises a support structure, and the support structure and the base are formed from a single wafer.
4. The system of claim 1, wherein the mirror assembly comprises a support structure and a reflective surface on the support structure.
5. The system of claim 1, wherein the mirror assembly comprises a support structure having a metallized surface.
6. The system of claim 1, wherein the mirror assembly comprises a support structure and a mirror bonded to the support structure.
7. The system of claim 1, wherein the mirror assembly includes a mirror having an optical power.
8. The system of claim 1, wherein the mirror assembly includes a stress compensation layer.
9. The system of claim 1, wherein the mirror assembly includes a stiffening structure formed therein.
10. The system of claim 1, wherein the mirror assembly comprises a support structure, and the support structure and the base are formed from a same material.
11. The system of claim 1, wherein the mirror assembly is rectangular, square, round, oval, or octagonal.
12. The system of claim 1, wherein the at least one spring comprises an

electroplated metal.
13. The system of claim 12, wherein the metal comprises nickel.
14. The system of claim 1, wherein the torsional mirror support assembly comprises two collinear torsional springs aligned with a centerline of the mirror assembly on opposite sides thereof.
15. The system of claim 1, wherein the spring includes a narrowed section to reduce a spring constant of the spring.
16. The system of claim 1, wherein the spring includes a tapered portion from the base to the mirror assembly.
17. The system of claim 1, wherein the spring extends across the cavity in the base and the mirror assembly is bonded to the spring.
18. The system of claim 1, wherein the torsional mirror support assembly comprises two collinear torsion springs offset from a centerline of the mirror assembly on opposite sides thereof.
19. The system of claim 1, wherein the actuator assembly is operative to drive the torsional mirror support assembly at the resonant frequency of the mirror assembly.
20. The system of claim 1, wherein the resonant frequency ranges from 3 kHz to 60 kHz.
21. The system of claim 1, wherein the resonant frequency ranges up to 60 kHz.
22. The system of claim 1, wherein the actuator assembly is operative to cause the mirror assembly to rotate through an angle of up to 40.degree..
23. The system of claim 1, wherein the rotational motion of the mirror assembly is limited by the maximum angle of twist achievable by the torsional mirror support assembly.
24. The system of claim 1, wherein the mirror assembly ranges from 5 .mu.m x 5 .mu.m to 3 mm x 3 mm.
25. The system of claim 1, wherein the torsional mirror support assembly comprises a gimballed structure comprising a first set of collinear torsion springs mounted on a rotatable support frame to support the mirror assembly, the cavity including an opening formed in the support frame, and a second set of collinear torsion springs orthogonal to the first set and mounted to rotatably support the support frame for rotational movement with respect to the base.
26. The system of claim 25, wherein the actuator assembly includes an electrical current path from the second set of collinear torsion springs onto the support frame to the first set of collinear torsion springs.
27. The system of claim 25, further comprising wire-bond wire jumpers from the base to the support frame to provide an electrical current path to the support frame.
28. The system of claim 25, further comprising electrically conducting serpentine spring bridges from the base to the support frame to provide an electrical current path to the support frame.
29. The system of claim 1, wherein the at least one spring of the torsional mirror support assembly comprises a multi-layered structure including an electrical path to the mirror assembly.
30. The system of claim 1, further comprising a sensing assembly operative to sense rotation of the mirror assembly.
31. The system of claim 30, wherein the sensing assembly comprises a capacitive sensor, an optical sensor, or a magnetic sensor.
32. A video display including the system of claim 1.
33. A beam scanner including the system of claim 1.
34. An image scanner including the system of claim 1.
35. A torsional micro-mechanical mirror system comprising:
a base having a cavity formed therein;
a mirror assembly;
a torsional mirror support assembly comprising at least one torsional spring supporting the mirror assembly for rotational movement over and within the cavity, the cavity sized sufficiently to allow unimpeded rotation of the mirror assembly to a preselected maximum angle of deflection; and
an actuator assembly operative to apply a driving force to torsionally drive the torsional mirror support assembly, whereby torsional motion of the torsional mirror support assembly causes rotational motion of the mirror assembly, the actuator assembly further comprising:
a portion of the spring disposed over and spaced from a surface of the base, the portion comprising a first drive plate;
a second drive plate supported on the base in spaced relation from the first drive plate to define a capacitive gap between the first drive plate and the second drive plate; and

a drive circuit in electrical communication with the first and second drive plates and operative to apply an electrostatic force between the first drive plate and the second drive plate.
36. The system of claim 35, wherein the first and second drive plates comprise metallized regions.
37. The system of claim 35, wherein the second drive plate comprises two metallized regions on the surface of the base offset from the centerline of the mirror assembly.
38. The system of claim 35, wherein the torsional mirror support assembly comprises two collinear torsional springs on opposite sides of the mirror assembly, and each of the two collinear torsional springs are spaced above a surface of the base by a support member to set the capacitive gap.
39. A torsional micro-mechanical mirror system comprising:
a base having a cavity formed therein;
a mirror assembly;
a torsional mirror support assembly comprising at least one torsional spring supporting the mirror assembly for rotational movement over and within the cavity, the cavity sized sufficiently to allow unimpeded rotation of the mirror assembly to a preselected maximum angle of deflection; and
an actuator assembly operative to apply a driving force to torsionally drive the torsional mirror support assembly, wherein the actuator assembly comprises a movable capacitor plate supported by the base to push on the torsional mirror support assembly in response to an actuation signal from the actuator assembly.

40. A torsional micro-mechanical mirror system comprising:
a base having a cavity formed therein;
a mirror assembly;
a torsional mirror support assembly comprising at least one torsional spring supporting the mirror assembly for rotational movement over and within the cavity, the cavity sized sufficiently to allow unimpeded rotation of the mirror assembly to a preselected maximum angle of deflection;
an actuator assembly operative to apply a driving force to torsionally drive the torsional mirror support assembly, whereby torsional motion of the torsional mirror support assembly causes rotational motion of the mirror assembly; and
a damping mechanism for the torsional mirror support assembly.
41. The system of claim 40, wherein the damping mechanism comprises a damping material surrounding the spring.
42. The system of claim 40, wherein the damping mechanism comprises a damping material in a gap between the mirror assembly and the base and spaced away from the torsional mirror support assembly.
43. The system of claim 40, wherein the damping mechanism comprises a layer of damping material in the torsional mirror support assembly.
44. The system of claim 40, wherein the damping mechanism comprises a coating of damping material on the spring.
45. The system of claim 40, wherein the damping mechanism comprises a damping device attached to the base.
46. A torsional micro-mechanical mirror system comprising:
a base having a cavity formed therein and a surface defining a plane;
a mirror assembly;
a torsional mirror support assembly comprising at least one torsional spring supporting the mirror assembly for rotational movement about a rotational axis over and within the cavity, the cavity sized sufficiently to allow unimpeded rotation of the mirror assembly to a preselected maximum angle of deflection; and
an actuator assembly operative to apply a driving force to rotatably drive the mirror assembly, the actuator assembly comprising a first electrode supported on an edge of the mirror parallel to the rotational axis, and a second electrode supported on the edge of the cavity in the base parallel to the rotational axis in spaced relation from the first electrode to define a capacitive gap between the first electrode and the second electrode, the first electrode and the second electrode lying in the plane defined by the surface of the base when no driving force is applied to drive the mirror assembly.
47. A torsional micro-mechanical mirror system comprising:
a base having a cavity formed therein;
a mirror assembly;
a torsional mirror support assembly comprising at least one torsional spring supporting the mirror assembly for rotational movement over and within the cavity, the cavity sized sufficiently to allow unimpeded rotation of the mirror

assembly to a preselected maximum angle of deflection; and
an actuator assembly operative to apply a driving force to rotatably drive the mirror assembly, the actuator assembly comprising a movable capacitor plate supported on the base to push on the mirror assembly in response to an actuation signal from the actuator assembly.
48. A cantilevered micro-mechanical mirror system comprising:
a base formed of a substrate material and having a cavity formed therein;
a mirror assembly formed of the substrate material;
a cantilevered mirror support assembly comprising at least one cantilever spring supporting the mirror assembly for rotational movement over the cavity, the cantilever spring including an electrically conductive path from the base to the mirror assembly; and
an actuator assembly operative to apply a driving force to rotate the mirror assembly.
49. The system of claim 48, wherein the cantilevered mirror support assembly comprises a plurality of cantilever springs, each of the springs including a separate electrically conductive path from the base to the mirror assembly.
50. A scanning torsional micro-mechanical mirror display device comprising:
a base having a cavity formed therein;
a mirror assembly having a reflective layer;
a torsional mirror support assembly comprising a gimballed structure comprising a support frame rotatably supported with respect to the base by a set of collinear torsion springs, the support frame having an opening therein over the cavity in the base, a further set of collinear torsion springs orthogonal to the set of torsion springs and mounted on the rotatable support frame to support the mirror assembly for rotational movement within the opening and over and within the cavity, the cavity sized sufficiently to allow unimpeded rotation of the mirror assembly to a preselected maximum angle of deflection;
an actuator assembly comprising:
a magnetic driving assembly comprising an electromagnetic coil operative in cooperation with magnetic material attached to the rotatable support frame to apply a magnetic driving force to torsionally drive the set of torsion springs to rotatably drive the support frame, and
an electrostatic driving assembly operative to apply an electrostatic driving force to torsionally drive the further set of torsion springs to rotatably drive the mirror assembly;
a damping mechanism disposed to dampen the support frame; and
a packaging containing the base, the mirror assembly, the torsional mirror support assembly, and the actuator assembly under vacuum.
51. The device of claim 50, wherein the mirror assembly is 1 mm by 1 mm.
52. The device of claim 50, wherein the reflective layer comprises ah aluminum coating.
53. The device of claim 50, wherein the support frame has a resonant frequency in the range of 150 to 700 Hz.
54. The device of claim 50, wherein the resonant frequency of the support frame is approximately 400 Hz.
55. The device of claim 50, wherein the magnetic driving assembly is operative to drive the support frame at 60 Hz.
56. The device of claim 50, wherein the mirror assembly has a resonant frequency in the range of 7 to 15 kHz.
57. The device of claim 50, wherein the electrostatic driving assembly comprises metallized regions on the base below the further set of torsion springs.
58. The device of claim 50, wherein the dampening mechanism comprises a damping material between the base and the support frame.
59. The device of claim 50, further comprising wire bond wire jumpers from the base to the support frame to provide an electrical current path to the support frame.
60. A micro-mechanical mirror system comprising:
a base having a cavity formed therein;
a mirror assembly;
a mirror support assembly comprising two pairs of cantilever springs disposed on opposite sides of the mirror assembly, the springs of each pair offset from either side of a centerline of the mirror assembly, the springs capable of bending motion, to support the mirror assembly for rotational movement about the centerline over and within the cavity, the cavity sized sufficiently to allow unimpeded rotation of the mirror assembly to a preselected maximum angle of deflection, the springs further formed of a material to comprise electrically conducting paths to the mirror assembly; and

an actuator assembly operative to apply a driving force alternately to each spring of the pairs of spring to drive the mirror support assembly, whereby alternate bending motion of the springs of each pair of springs causes rotational motion of the mirror assembly about the centerline.

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L5: Entry 9 of 24 File: USPT Sep 28, 1999

US-PAT-NO: 5959760
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TITLE: Light beam scanner using large electrostatic force

DATE-ISSUED: September 28, 1999

INVENTOR-INFORMATION:

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US-CL-CURRENT: 359/224; 359/223

CLAIMS:

What is claimed is:
1. A light beam scanner comprising:
a supporting substrate;
fixed electrodes of a first set provided on said supporting substrate to oppose to each other;
a mirror provided between said fixed electrodes, having torsion bars physically connected to said supporting substrate and a mirror electrode section in end portions of said mirror opposing to said fixed electrodes at least, wherein said mirror rotatably vibrates between an upper position of said one fixed electrode and a lower position thereof by torsion force of said torsion bars and electrostatic force due to a voltage using said torsion bars as a rotation axis, when said voltage is applied between one of said fixed electrodes and said electrode section.
2. A light beam scanner according to claim 1, wherein said mirror and said fixed electrodes of said first set are arranged in a plan view such that said mirror and said fixed electrodes do not overlap.
3. A light beam scanner according to claim 2, wherein a shape of each of said end portions of said mirror and a shape of the opposing one of said fixed electrodes of said first set are determined such that a capacity between said end portion and said opposing fixed electrode can be made larger.
4. A light beam scanner according to claim 3, wherein each of said end portions of said mirror and each of said fixed electrodes of said first set have comb shapes.
5. A light beam scanner according to claim 1, wherein said fixed electrodes of said first set are provided to have lower surfaces higher than an upper surface of said mirror when no voltage is applied between said electrode section of said mirror and said fixed electrodes of said first set.
6. A light beam scanner according to claim 5, wherein said end portions of mirror extend upward.
7. A light beam scanner according to claim 5, further comprising fixed electrodes of a second set provided to said supporting substrate to have upper surfaces lower than a lower surface of said mirror when no voltage is applied between said electrode section of said mirror and said fixed electrodes of said second set.
8. A light beam scanner according to claim 7, wherein said voltage is applied between said electrode section of said mirror and one of said fixed electrodes of said first set and one of said fixed electrodes of said second set opposing to said one fixed electrode of said first set.
9. A light beam scanner according to claim 1, wherein one of said fixed

electrodes of said first set is provided to have a lower surface higher than an upper surface of said mirror, when no voltage is applied between said electrode section of said mirror and said fixed electrodes of said first set.
10. A light beam scanner according to claim 1, wherein one of said fixed electrodes of said first set is provided to have an upper surface lower than a lower surface of said mirror, when no voltage is applied between said electrode section of said mirror and said fixed electrodes of said first set.
11. A light beam scanner according to claim 1, further comprising:
another supporting substrate having fixed electrodes of a third set provided on said other supporting substrate to oppose to each other, and wherein said supporting substrate is provided between said fixed electrodes of said third set, and further comprises:
a substrate electrode section in end portions of said supporting substrate opposing to said fixed electrodes of said third set at least; and
second torsion bars extending in a direction perpendicular to said torsion bars, and
wherein said supporting substrate rotatably vibrates between upper and lower positions of said fixed electrodes of said third set by torsion force of said second torsion bars and electrostatic force due to a voltage applied between said substrate electrode section and said fixed electrodes of said third set.
12. A light beam scanner according to claim 11, wherein said supporting substrate and said fixed electrodes of said third set are arranged in a plan view such that said supporting substrate and said fixed electrodes of said third set do not overlap.
13. A light beam scanner according to claim 1, further comprising a voltage applying unit for applying a pulse voltage to said electrode section of said mirror and said fixed electrodes of said first section such that said mirror is rotatably vibrated.
14. A light beams scanner according to claim 13, wherein said voltage applying unit applies said pulse voltage to said electrode section of said mirror and the one of said fixed electrodes of said first set such that said mirror starts the vibration from an original position, and stops said application of said pulse voltage when one of said end portions of said mirror reaches said one fixed electrodes.
15. A light beams scanner according to claim 14, wherein said voltage applying unit applies said pulse voltage to said electrode section of said mirror and said one fixed electrode of said first set immediately before said one end portion of said mirror returns to said one fixed electrode and stops said application of said pulse voltage when said one end portion of said mirror returns to said original position.
16. A light beams scanner according to claim 15, wherein said voltage applying unit applies said pulse voltage to said electrode section of said mirror and the one of said fixed electrodes of said first set when said one end portion of said mirror returns to said original position and stops said application of said pulse voltage when the other of said end portions of said mirror reaches said other fixed electrode of said first set.